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Potential Analysis of Mediterranean Forestry for Offsetting GHG Emissions at Regional Level: Evidence from Valencia, Spain

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Abstract: Forest management is an untapped tool, yet to realize its full potential to fight against climate change. The capability of forests to act as carbon sinks makes them a key resource to reduce CO_2 concentration in the atmosphere. However, carbon which has been fixed can be suddenly emitted again as a consequence of disturbances such as pests or wildfires. Mediterranean plant phenology, climatic conditions, and the accumulation of fuel biomass due to abandonment of traditional forest uses generate a scenario prone to large wildfires and consequently large greenhouse gases (GHG) emissions. The abandonment could be offset by considering the economic value of forest ecosystem services, principally carbon fixation. Nevertheless, currently existing forest carbon markets consider only anthropogenic fixation based on a business as usual scenario without disturbances that cannot be applied to Mediterranean forest reality. Thus, a methodology to monetize carbon fixed has been developed and applied. A range between 55.5 and 250 million € produced by the monetization of 16.5 million potential carbon credits has been obtained based on anthropogenic avoided emissions produced over a 10 year-period. Thereby, the potential for offsetting emissions of the pilot region was between 1.2% and 5.6% of total diffuse GHG emissions. Consequently, sustainable forest management represents an important opportunity to combat climate change, taking advantage of the margin of improvement that the Mediterranean forests currently have to avoid GHG emissions through forest fire prevention silviculture.

Keywords: Mediterranean forestry; GHG; carbon; climate change; wildfires

1. Introduction

Forests play a key role in climate change mitigation by sequestrating atmospheric carbon dioxide (CO_2) in new forestland and in extant forests [1]. According to the Intergovernmental Panel on Climate Change (IPCC) [2], carbon stored in terrestrial ecosystems is distributed betwee three compartments: living plant biomass (stem, branches, foliage, roots); plant detritus (fallen branches and cones, forest litter, tree stumps, tree tops, logs); and soil (organic mineral, surface and deep mineral soil). The terrestrial biosphere has the potential to mitigate between 10 and 20% of the fossil fuel emissions by 2050 [1]. Following Vine et al. [3], forests can tackle climate change in three main ways:

(a) afforestation, reforestation or forest management to increase the carbon fixed by forests;

(b) bioenergy or biomaterials as substitutive of fossil fuels or more energy intensive materials [4–6]; and

(c) preservation of existing forests to avoid or reduce emissions due to anthropogenic disturbances (deforestation) or natural disturbances (pests, hurricanes, snowfalls or wildfires) through preventive and sustainable forest management.

Forest fires have social, ecological and economic costs [7]. In ecological terms, preserving existing forests is especially important because forests act as both sinks or sources of greenhouse gas (GHG) emissions [8,9]. Natural forest disturbances (mainly wildfires) emit 9 Gt C per year worldwide, which represents approximately 30% more than the GHG emissions from fossil fuels [10]. Wildfire risk is clearly the result of the interaction between human activities, largely a result of mismanagement over decades or centuries, ecological domains, and climate [11]. In fact, in especially vulnerable areas such as the Mediterranean, wildfire risk is increasing mainly due to three causes [12]:

(a) number of years with increased fire risks;
(b) season length with severe meteorological conditions that increase fire risks; and
(c) extreme events (e.g., total number of days with Fire Weather Index (FWI) >45 and especially episodes with FWI >45 for seven consecutive days) during summer or drought seasons are increasing.

In 2009 alone, approximately 434,927 ha were burnt in the EU Mediterranean region [13]. For this reason, wildfires are one of the most detrimental environmental issues in the Mediterranean basin.

Mediterranean plant phenology and climatic conditions generate a scenario very prone to large wildfires and consequently large amounts of GHG emissions. In addition, the accumulation of fuel biomass due to abandonment of traditional forest uses affects severity and magnitude of wildfires, as Marchi et al. [14] demonstrate in Mediterranean Country, and therefore causes even higher emissions. This abandonment is partly a result of the low economic revenues of Mediterranean forests and it could be solved by considering the ecosystem services of forests, principally carbon fixation.

There are ways to quantify in money terms the carbon fixed by forest systems. The most commonly used mechanism is carbon markets [15]. A carbon market is a financial solution for GHG reduction through emissions trading [16]. In other words, it is a market in which carbon credits are obtained and sold within defined standards for GHG prevention or reduction [17]. There are two different types of carbon markets [18]:

a. regulatory compliance market: used by companies and governments that by law have to account for their GHG emissions and is regulated by mandatory national, regional or international carbon reduction regimes.
b. voluntary market: carbon credits trade is on voluntarily basis.

In Europe, the most important compliance market is the European Union Emissions Trading Systems (EU ETS) for direct GHG emissions [19]. EU ETS works at setting a cap on the total amount of GHG emissions that can be emitted by installations and receiving a part of its emissions in free allocated allowances forced to reduce the rest. At least half of the auction revenues of EU ETS must be used to reduce GHG emissions for mitigation or adaptation to climate change in the EU and third countries [19]. But even though wildfires can be a major focus of GHG emissions mainly in the European Mediterranean regions, none of this money goes to wildfire prevention [16].

On the other hand, the most important type of voluntary carbon market is based on forest fixation [20]. The total carbon credits generated in forest based voluntary carbon markets correspond to the difference in carbon stock regarding business as usual (BaU) due to different silvicultural practices (reforestation after clear cutting, tree plantations on former agricultural land etc.). Nevertheless, despite the existence of some preservation actions in the same carbon markets (as in the EU ETS carbon market) [19], especially aimed at the preservation of tropical forests, most of the forest actions to compensate GHG emitted of voluntary carbon markets are limited methodologically to reforestation or tree plantations actions, as for example in Spain [21]. Nevertheless, this approach does not

include sustainable forest management to reduce wildfire risk, to improve forest health or to provide the sustainability of non-economical ecosystem services of forests.

Therefore, this approach is not useful in large areas of the Mediterranean basin, especially in dry regions with a low rate of forest management due to the low economic value (with high rates of rural abandonment) and yearly accumulation of fuel biomass. These forests are specifically prone to wildfires, even more under severe weather conditions foreseen with climate change that will increase burned area and fire severity [22–25].

Another system for monetize the carbon stored in the forest sector is Reducing Emissions from Deforestation and forest Degradation (REDD +). The REDD + initiative applies a market-based approach to reducing GHG emissions from deforestation and forest degradation [26]. The difference between the carbon stock of forests under historical deforestation and forest degradation rates and the actual C-stock achieved by forest conservation measures will be compensated financially. The difference in C-stocks is provided by a system of measurement, reporting, and verification (MRV). However, the cost of MRV is too high in countries with low deforestation compared to the economic compensation of REDD + [26]. This means that REDD + only has an impact in developing countries where historically there has been high deforestation ratios and its economic compensation is worth it [26].

There is a high potential for annual fixation by Mediterranean forests to mitigate climate change that needs to be estimated and valued because it can become a great source of GHG emission [12]. But for this to occur, it is necessary to develop a monetization methodology with a new approach adapted to Mediterranean forest types, which takes into account prevention measures to reduce GHG emissions by natural disturbances, mainly wildfires.

The overall objective of this research is to analyze the potential of Mediterranean forestry for offsetting GHG emissions at a regional level with local level resolution. To achieve this, the specific aims are:

1. to quantify CO_2 fixation in the total biomass of forests in the study area under Mediterranean conditions;
2. to develop and to apply a methodology to monetize the CO_2 eq. fixation of forests under Mediterranean conditions;
3. to compare total forest CO_2 fixation with total GHG emissions at the regional level in the case study region; and
4. to evaluate the potential of Mediterranean forestry for offsetting GHG emissions.

2. Materials and Methods

The materials and methods section is structured in the six steps described in the diagram of Figure 1. Thus, in first place the annual carbon fixation was calculated for small and tall trees. Then, the total carbon stored till today was quantified by municipality. After that, a monetization model was developed and applied to obtain the potential carbon saved (PCS) and the potential carbon credits (PCCs) available. Finally, the total number of carbon credits generated (NCCG) of the regional case study was quantified.
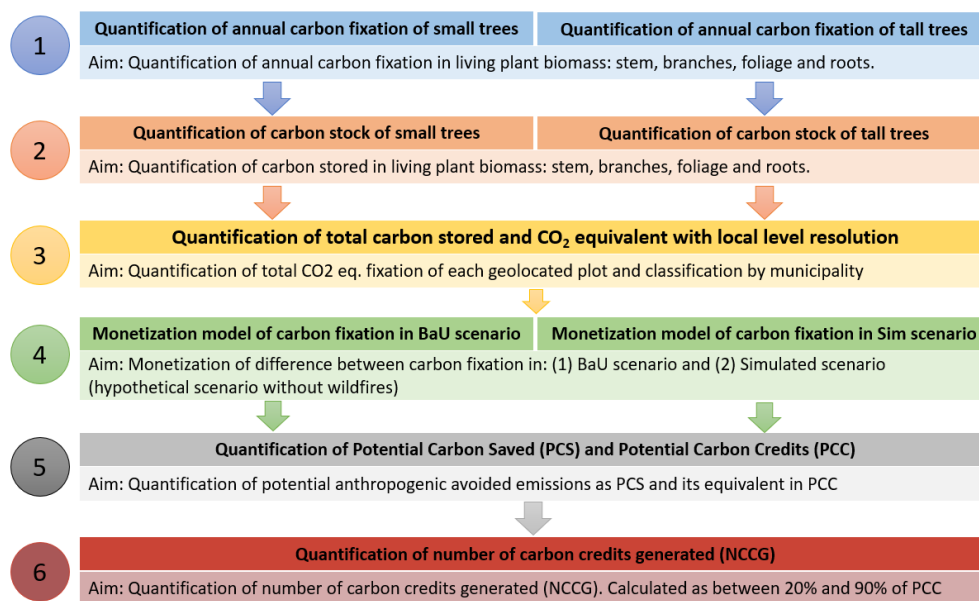
Figure 1. Diagram of the methodology steps.

2.1. Regional Case Study

To carry out this research, the Valencia Region in eastern Spain has been identified and chosen as a case study, since Valencia has an important forest area (1.2 million hectares, 57% of the total area) and well represents Mediterranean forestry [27]. The 72% of woodlands are dominated by *Pinus halepensis* Mill., while *Quercus ilex* L. represents the main species in only the 14% of this area [28]. Valencia has a population of about 5 million people that live on an area of more than 23 thousand km². Most of its inhabitants live in coastal municipalities, where intensive agriculture and industry developed, as well as services and tourism. The interior of the region is very mountainous, dominated by an agroforestry landscape, but with very pronounced rural abandonment during the last five decades. Rural municipalities occupy 61.85% of the Valencian territory, while only contain 6.82% of the total population [28]. Additionally, between 18% and 24.8% of rural inhabitants are older than 65, which has led to an ageing population. This situation has propitiated that many agricultural lands get evolved into forest without any type of management by the rural owners (see Figure 2) [29]. In fact, in last decade forest area has had an average increase of 3300 ha/year [28], mainly being converted into coniferous woodlands. Land ownership also affects forest management in Valencia Region. It is characterized by being mainly private, smallholder, and disaggregated. In Valencia, 55.2% of forest areas belong to private owners, 36.8% to public entities (mainly to municipalities), and 6.3% to unknown proprietors [28]. Moreover, more than half of the private lands have less than 1 ha. area and approximately one third of the forest area are located within agriculture and agroforestry parcels [28], which makes it more difficult to manage. Climate is the typical Mediterranean climate characterized by having mild winters, warm autumns, rainy springs, and dry and hot summers, in which forest fires abound. As for all Mediterranean regions, Valencia is classified as one of the most negatively affected by climate change in Europe [30].
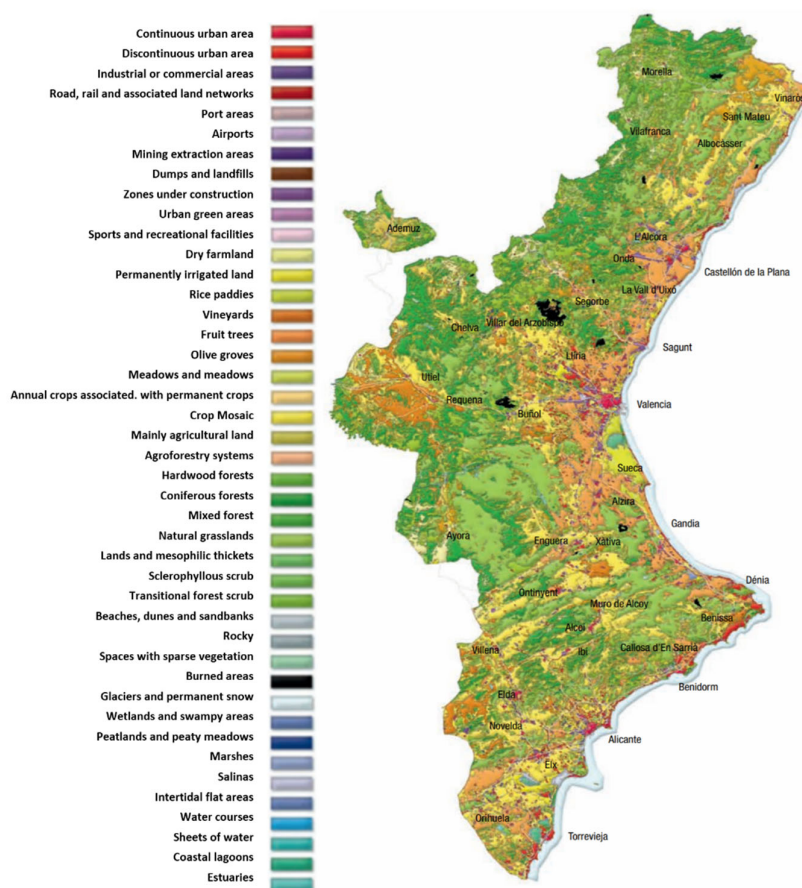
Figure 2. Land cover map of the region of Valencia (Spain) [31].

2.2. Quantification of Carbon Fixation in Forest Biomass under Mediterranean Conditions

The quantification of CO_2 eq. sequestered in forestry in this regional case study has been focused on the carbon stored in living plant biomass: stem, branches, foliage, and roots. Thus, firstly annual growth in terms of dry weight of biomass has been calculated differentiating between small trees (diameter at breast high (DBH) <7.5 cm) and tall trees (DBH >7.5 cm). The methodology described by Montero et al. [32] has been followed to quantify annual growth of small trees. To quantify the annual growth of tall trees, the methodology described by Lerma-Arce [33], used to calculate cumulative biomass existence, has been adapted to calculate the annual growth of biomass (in dry weight). Then, a carbon fraction of dry weight biomass of 0.5 (weight Carbon/weight dry biomass) as the mean value of different authors consulted [2,32,34–39] has been used. Finally, the stoichiometric relationship between carbon and CO_2 is used to obtain the amount of CO_2 equivalent (CO_2 eq.) that is fixed annually.

The data for the application of these methodologies were obtained from the National Forest Inventory database in Spain (IFN3) [40]. The IFN3 characterizes a number of stands that describe forest ecosystems present in each region, according to the species present, their respective occupations and their age stage (see Table 1). Then, the forest area of the region is divided into different geolocated plots. Each plot is characterized by the stand to which it belongs and its area. Thus, carbon fixation of small and tall trees classified by diametric classes has been quantified per plot.

Table 1. Stands defined to Valencia Region. Source: IFN3 [40].

Stand	Dominant Species	Occupation (%)	Stage	Canopy Cover (%)
01	*Pinus halepensis*	≥70	Old growth	70–100
02	*Pinus halepensis*	≥70	Old growth	40–69
03	*Pinus halepensis*	≥70	Old growth	20–39
04	*Pinus halepensis*	≥70	Young forest	5–100
05	*Pinus nigra and P. pinaster* or mixed with *Pinus halepensis*	≥70; 30 ≤ Sp.<70	Old growth	40–100
06	*Pinus nigra and P. pinaster* or mixed with *Pinus halepensis*	≥70; 30 ≤ Sp.<70	Old growth	20–39
07	*Quercus ilex* or mixed with *Pinus halepensis* or *Ceratonia siliqua*	≥70; 30 ≤ Sp.<70	Old growth	20–100
08	*Quercus ilex* or mixed with *Pinus spp.*	≥70; 30 ≤ Sp.<70	Young forest	5–100
09	*Juniperus thurifera*	≥70	Old growth, Young Forest	20–100 5–100
10	Riverside trees (*Populus spp., Fraxinus spp…*)	≥70; 30 ≤ Sp.<70	All	5–100
11	Scrub	≥70; 30 ≤ Sp.<70	Old growth	5–19

Table is originally cited from Tercer Inventario Forestal Nacional as per the Spanish Government.

2.2.1. Quantification of Carbon Fixation of Small Trees

The quantification of the carbon fixed by the small trees (DBH < 7.5cm) was obtained from equation (1):

$$Carbon\ Fixation_{st}\ (t\ C/year)\ =\ \sum_{plots} AIDWst_k \times N^{\underline{o}}st_j \times Area_i \times CF \tag{1}$$

where:

AIDWst: Annual increment of dry weight of a small tree (DBH < 7.5 cm), in tonnes per year

N$^{\underline{o}}$st: Number of small trees per hectare

Area: Area of plot in hectares

CF: Carbon fraction of dry weight biomass (0.5 t C/ t dry biomass)

i: plot

k: species

j: stand

The annual increment of dry weight of small trees was obtained from the models developed by Montero et al. [32], which measure the average annual increment of dry weight of different species with DBH < 7.5 cm. The number of small trees per hectare were obtained from the characterization of the stand to which that plot belongs in IFN3 [40] (see Table 2). IFN3 also offers the area of each plot.

Table 2. Example of forest stands characterization in Valencia. Source: adapted from IFN3 [40].

Species or Group of Species	Nºrt: Number of Tall Trees Per Hectare (Nªtt/ha)	VWB (m³)	AIVCrt (m³)	Nºst: Number of Small Trees Per Hectare (N°st/ha)
Pinus halepensis	605.55	67.962	2.349	286.48
Pinus pinaster	1.39	0.305	0.010	3.82
Pinus nigra	0.07	0.015	0.000	0.00
Quercus ilex	3.17	0.108	0.002	38.20
Juniperus thurifera	1.27	0.021	0.001	138.78
Ceratonia siliqua	2.80	0.212	0.002	5.09
Riverside trees (*Populus spp., Fraxinus spp…*)	0.03	0.071	0.001	4.46
Other hardwood trees	2.23	0.075	0.001	12.73
Total	616.51	68.773	2.366	489.56

2.2.2. Quantification of Carbon Fixation of Tall Trees

The quantification of the carbon fixed by tall trees (DBH > 7.5cm) was obtained from equation (2):

$$Carbon\ Fixation_{nst}\ (t\ C/year) = \sum_{plots} AIVCtt_{j,k} \times BD_k \div \%stem_k \times Area_i \times CF \tag{2}$$

where:

AIVCtt: Annual increment of volume of the stem of tall trees, in m³/ha.
BD: Basic density
Area: Area of plot in hectares
%stem: percentage of the stem weigh over the rest of the tree biomass (see Table 3).
CF: Carbon fraction of dry weight biomass (0.5 t C/ t dry biomass)
i: plot
k: species
j: stand

The AIVCtt by species was obtained from IFN3 [40]. The percentage of the stem weight over the rest of the tree biomass by species was obtained from the models of Montero et al. [32]. The area of each plot is also obtained from IFN3. Table 3 shows the relative value in dry weight of each part of the tree adapted from Montero et al. [32].

Table 3. Relative value that represents the dry weight of each part of the tree. Adapted from Montero et al. [32].

Species	Stem	Aerial Biomass			Leaves	Total	Radical Biomass
		Branches					
		R > 7 cm	R 2–7 cm	R< 2 cm			
Pinus halepensis	37%	9.80%	8.40%	21.20%	0%	76.40%	23.60%
Pinus nigra	51.10%	5.40%	8.00%	15.90%	0%	80.40%	19.60%
Pinus pinaster	61.9%	0.9%	4.1%	10.9%	0.0%	77.9%	22.1%
Pinus pinea	36.4%	17.7%	11.4%	13.4%	5.6%	84.5%	15.5%
Pinus sylvestris	56.1%	2.5%	7.0%	7.4%	5.6%	78.6%	21.4%
Populus x euramericana	48.9%	6.4%	6.4%	6.1%	2.3%	76.0%	24.0%
Quercus ilex	18.4%	24.2%	12.2%	8.7%	2.0%	65.4%	34.6%

Quercus faginea	25.1%	24.7%	9.9%	5.5%	3.2%	68.4%	31.6%
Quercus suber	32.4%	30.8%	10.5%	2.4%	1.4%	77.5%	22.5%
Juniperus thurifera	35.8%	7.8%	14.6%	9.3%	8.5%	76.1%	23.9%
Juniperus oxycedrus	-	-	-	-	-	21.8%	78.2%
Ceratonia siliqua	17.7%	13.1%	7.4%	7.7%	5.3%	51.2%	48.8%
Olea europaea	19.6%	25.0%	13.3%	9.3%	1.3%	68.6%	31.4%
Fraxinus excelsior	24.4%	11.7%	11.8%	9.9%	0.0%	57.8%	42.2%

2.3. Quantification of Total Carbon Fixed and CO$_2$ Equivalent with Local Level Resolution

The quantification of the total carbon fixed by living plant biomass of forestry was obtained from equation (3):

$$Carbon\ Fixation_{total}\ (t\ C/year) = Carbon\ Fixation_{st} + Carbon\ Fixation_{tt} \quad (3)$$

Then, equation (4) shows how many tons of CO$_2$ eq. are obtained from the amount of carbon calculated in equation (3). Note that it must be multiplied by the relationship between the weight of the CO$_2$ molecule and the weight of the C atom (44/12):

$$CO2\ eq.\ Fixation\ (t/year) = Carbon\ Fixation \times \frac{44}{12} \quad (4)$$

The total CO$_2$ eq. fixation of each geolocated plot is intersected with the local administrative layer of the Geographic Information System (GIS), which includes all of the 562 municipalities of the region. With this geographical segmentation, the developed model is able to calculate the total CO$_2$ eq. fixation of local forests with high spatial resolution.

2.4. Monetization of Carbon Fixation in Mediterranean Forests

To monetize the carbon fixation of the Mediterranean forest, an innovative methodology has been developed. This aims to analyze the potential to generate carbon credits as anthropogenic avoided emissions due to reduced wildfire risk compared with a BaU scenario. To achieve this, firstly a literature review to obtain carbon credit prices based on existing carbon markets has been carried out. Several forestry based carbon markets [41–43] have been analyzed and the carbon credit price has been calculated based on the price of these markets.

Up to today, the calculation of carbon credits generated by forestry has been based on the difference of the theoretical growth scenario without any type of silvicultural measure (BaU) with respect to a scenario affected by different measures (mainly afforestation and reforestation) [41–43]. Increasing the number of trees is an adequate measure for forests where the species have an important economic value and therefore product-oriented harvesting is guaranteed, e.g., in central and northern European countries [44]. However, in most southern Mediterranean countries, wood has a normally low economic value and consequently low harvesting rates [45]. This low level of management implies the accumulation of combustible biomass, which directly influences a higher vulnerability to fire in the Mediterranean forest ecosystems, especially in times of severe drought [46]. Realistically, the reduction of wildfire risk and magnitude would be a highly effective measure to mitigate climate change, since the emission of a large amount of GHG would be avoided [47]. For this reason, the developed methodology calculates the BaU scenario taking into account the extent of wildfires in the region over

the last 10 years. This scenario is compared with a simulated case without wildfires. The range between the carbon stocks stored in both scenarios represents the number of potential carbon credits that could be generated as anthropogenic avoided emissions in a 10-year period. This period has been chosen because it is the period of time usually used in the forest management plans [48] and it allows excessive influence of anomalous events to be avoided depending on the moment that the methodology would be applied. For example, in the case of an extraordinary wildfire event in the previous year and taking only this year as BaU scenario, results of carbon credits available would be unrealistic and highly influenced by this event.

2.4.1. Model for Monetization of Carbon Fixation in a business as usual (BaU) Scenario

Equation (5) exposes the developed model for monetization of carbon fixation in a BaU scenario.

$$f(x) = \frac{(C_{t0} - C_{tm})}{(t_0 - t_m)} \times (x - t_0) + C_{t0} \tag{5}$$

where:

f (x): Carbon stored determined by the year (x) in the BaU scenario.

t_0: Base year (first year of the period)

t_m: Any year of the 10-year period

C_{t0}: Carbon stock in the base year. Calculated following the methodologies described by Montero et al. [32] and Lerma-Arce [33]. C_{t0} is calculated by equation (6).

$$C_{t0} \ (t \ C) = Carbon \ Stock_{t0,st} + Carbon \ Stock_{t0,tt} \tag{6}$$

where:

Carbon Stock $_{t0,st}$: Carbon stock in the base year of small trees. Calculated by the equation (7)

Carbon Stock $_{t0,tt}$: Carbon stock in the base year of tall trees. Calculated by the equation (8).

$$Carbon \ Stock_{st} \ (t \ C) = \sum_{plots} N^\circ st_j \times Area_i \times MC \times \pi \times R^2 \times h \times CF \tag{7}$$

where:

N°st: Number of small trees per hectare

Area: Area of plot in hectares

CF: Carbon fraction of dry weight biomass (0.5 t C/ t dry biomass)

MC: Morphic Coefficient

R: Radius in meters (0.025 m based on Montero et al. [32])

h: Height in meters (1.6 m based on Montero et al. [32])

i: plot

j: stand

$$Carbon \ Stock_{tt} \ (t \ C) = \sum_{plots} VWB_{j,k} \times BD_k \div \%stem_k \times Area_i \times CF \tag{8}$$

where:

VWB: Volume with bark of stem in cubic meters (see Table 2)

BD: Basic density

Area: Area of plot in hectares

%stem: percentage of the stem weigh regarding the rest of the tree biomass (see Table 3)

CF: Carbon fraction of dry weight biomass (0.5 t C/ t dry biomass)

i: plot

k: species

j: stand

C_{tm}: Carbon stock in the year m, obtained from equation (9).

$$C_{tm} = C_{t(m-1)} - \overline{C\ burned} - \overline{Cp} - \overline{Cb} + Carbon\ fixation_{total} \tag{9}$$

where:

$C_{t(m-1)}$: Carbon stock in the year before m

$\overline{Cp}$: Average of carbon stock extracted from forest to products manufacturing (see Table 4)

$\overline{Cb}$: Average of carbon stock extracted from forest to bioenergy (see Table 4)

$\overline{C\ burned}$: Average of carbon losses by wildfires calculated as equation (10).

$$\overline{C\ burned} = \frac{C_{t0}}{For.Area} * \overline{BA} * \overline{\%BC} \tag{10}$$

where:

For.Area: Forestry area of total region in hectares (see Table 4)

$\overline{BA}$: Average of burned area over the 10 years in hectares (see Table 4)

$\overline{\%BC}$: Average of biomass consumed during wildfire due to severity (see Table 4).

C_{t0}: Carbon stock in the base year.

Table 4. Value used in variables to the study case of Valencia.

Variable	Value	Reference
Average of carbon stock extracted from forest to products manufacturing	417,273 t C/year	[49]
Average of carbon stock extracted from forest to bioenergy	71,300 t C/year	[49]
Forestry area of total region in hectares	1,200,194 ha	[40]
Average of burned area of the 10 years in hectares	9,732 ha/year	[50]
Average of biomass consumed during wildfire due to severity	72.6%	Calculated in REMAS Interreg SUDOE project currently in progress [51]

2.4.2. Model for monetization of carbon fixation in a simulated scenario

Equation (11) exposes the developed model for monetization of carbon fixation in a simulated scenario, which represent a hypothetical scenario without wildfires.

$$g(x) = \frac{(C_{t0} - CSim_{tm})}{(t_0 - t_m)} \times (x - t_0) + C_{t0} \tag{11}$$

where:

g (x): carbon stored determined by the year (x) in the simulated scenario.

t_0: Base year (first year of the period)

t_m: Any year of the 10-year period

m: Year

C_{t0}: Carbon stock in the base year.

$CSim_{tm}$: Carbon stock in the year m in a scenario simulated without wildfires obtained from equation (12).

$$CSim_{tm} = CSim_{t(m-1)} - \overline{Cp} - \overline{Cb} + Carbon\ fixation_{total} \tag{12}$$

where:

$CSim_{t(m-1)}$: Carbon stock in the year before m in the simulated scenario

$\overline{Cp}$: Average of carbon stock extracted from forest to products manufacturing (see Table 4).

$\overline{Cb}$: Average of carbon stock extracted from forest to bioenergy (see Table 4).

Thus, the total potential carbon saved (PCS) is calculated with equation (13), being the area between the two scenarios functions f(x) and g(x).

$$Potential\ Carbon\ Saved = \int_{year\ 0}^{year\ 9} [g(x) - f(x)]dx \tag{13}$$

Therefore, the number of potential carbon credits (PCCs) corresponding with potential anthropogenic avoided emissions are obtained from equation (14):

$$Potential\ Carbon\ Credits\ (PCC) = Potential\ Carbon\ Saved \times \frac{44}{12} \tag{14}$$

Finally, the number of carbon credits generated (NCCG) will be between 20% and 90% of the amount of Potential Carbon Credits (PCC) (in t CO_2 eq.) in the simulated 10-year period. A maximum of 90% is used because the fire risk cannot be completely reduced [52]. The minimum 20% of the PCC available is due to fuel biomass reduction by fire prevention measures and consequent forest resilience improvement. Therefore, the NCCG will be defined by equation (15):

$$20\%\ PCC \leq \boldsymbol{NCCG} \leq 90\%\ PCC \tag{15}$$

2.5. Comparison between Carbon Fixation with Total GHG Emissions

The amount of annual CO_2 fixation has to be compared with the total amount of GHG emissions (direct and diffuse) in the case study region. It is important to differentiate because direct GHG emissions have their own mandatory carbon market (EU ETS), but diffuse GHG emissions could be a potential voluntary carbon market at the regional level. So, on the one side, direct GHG emissions of EU ETS industries have been quantified by digitalizing the annual GHG emissions notifications of the companies obligated to report their GHG emissions based on the 2003/87/EC Directive [53]. These notifications were obtained from OECC [54]. Conversely, diffuse GHG emissions have been calculated with national GHG emissions inventory based on a per inhabitants' ratio [55].

2.6. Evaluation of the Potential of Mediterranean Forestry for Offsetting GHG Emissions

Finally, the potential of Mediterranean forestry for offsetting GHG emissions through the monetization of anthropogenic-avoided emissions has been evaluated with the previous expressed models.
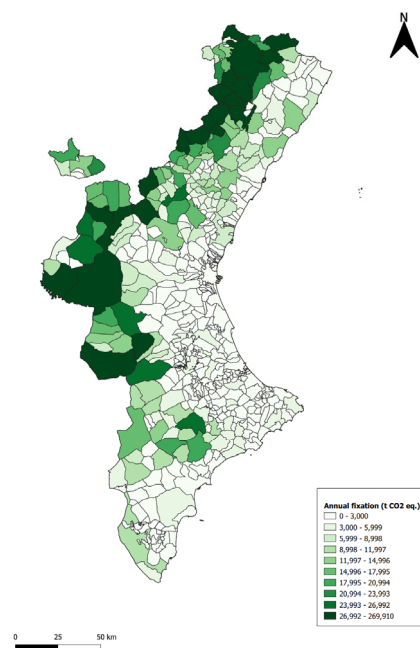
3. Results and Discussion

3.1. Total Carbon Fixation by Forest Biomass

The results of the application of the methodologies described for the Valencia region show a total amount of annual fixation of 3.16 million t of CO_2 eq. distributed at the local level (see Figure 3). This carbon fixation is distributed in 1.52 million t of CO_2 eq. produced by small trees and 1.64 million t of CO_2 eq. produced by tall trees.

CO_2 eq. fixation has been calculated in 473 municipalities with forests, from a total of 542 municipalities in the region. This represents 87.27% of total municipalities. Table 5 shows the most CO_2 eq. fixation municipalities in the region. These 19 municipalities represent the CO_2 eq. fixation of 40% of total fixation. Actually, the higher CO_2 fixation is produced in rural municipalities in the western mountainous areas (see Figure 3), which are less populated. For this reason, the monetization of the forest services as CO_2 fixation could be a very good option to mitigate and to adapt to climate change and to reduce rural depopulation.

Table 5. Municipalities of Valencia (Spain) with the highest CO_2 eq. fixation .

Municipality Name	Annual CO_2 eq. Fixation (t CO_2 eq./Year)	Relative Value Regarding Total CO_2 eq. Fixation (%)	Cumulative Relative Value of CO_2 eq. (%)
Morella	269,910	8.53	8.53
Requena	111,459	3.52	12.06
Pobla de Benifassà	93,688	2.96	15.02
Vistabella del Maestrat	93,421	2.95	17.97
Vallibona	78,851	2.49	20.47
El Toro	72,732	2.30	22.77
Ares del Maestrat	66,485	2.10	24.87
Ayora	60,373	1.91	26.78
Villahermosa del Río	56,822	1.80	28.57
Vilafranca	44,387	1.40	29.98
Venta del Moro	43,399	1.37	31.35
Castellfort	40,518	1.28	32.63
Cortes de Arenoso	40,414	1.28	33.91
Zorita del Maestrazgo	37,056	1.17	35.08
Chelva	36,819	1.16	36.24
Culla	36,259	1.15	37.39
Benassal	30,870	0.98	38.37
Andilla	30,498	0.96	39.33
Tuéjar	28,774	0.91	40.24

Figure 3. Spatial distribution of annual CO_2 eq. fixation with local level resolution in Valencia region (Spain).

3.2. Value of Carbon Fixed by Mediterranean Forests

The average carbon credit price calculated for year 2020 based on the forest carbon markets analyzed [41–43] is 16 €/t CO_2 eq. Thus, this price has been used to estimate the monetization of GHG emissions balance of the region with local level resolution.

The results of carbon stored in a BaU and in a simulated scenario for the 10-year period analyzed in the pilot region can be seen in Table 6.

Table 6. Results of carbon stored quantification in business as usual (BaU) and simulated scenarios, 2006 to 2015.

BaU Scenario			Simulated Scenario		
2006	C_{t0} (t C)	18,877,336	2006	C_{t0} (t C)	18,877,336
2007		19,123,160	2007		19,234,277
2008		19,368,985	2008		19,591,219
2009		19,614,810	2009		19,948,161
2010		19,860,634	2010		20,305,103
2011	C_{tm} (t C)	20,106,459	2011	$CSim_{tm}$ (t C)	20,662,045
2012		20,352,284	2012		21,018,986
2013		20,598,108	2013		21,375,928
2014		20,843,933	2014		21,732,870
2015		21,089,758	2015		22,089,812

Thus, the total Potential Carbon Saved (PCS) is 4.5 million t of C, being the area between the two scenarios functions f(x) and g(x) (see Figure 4)
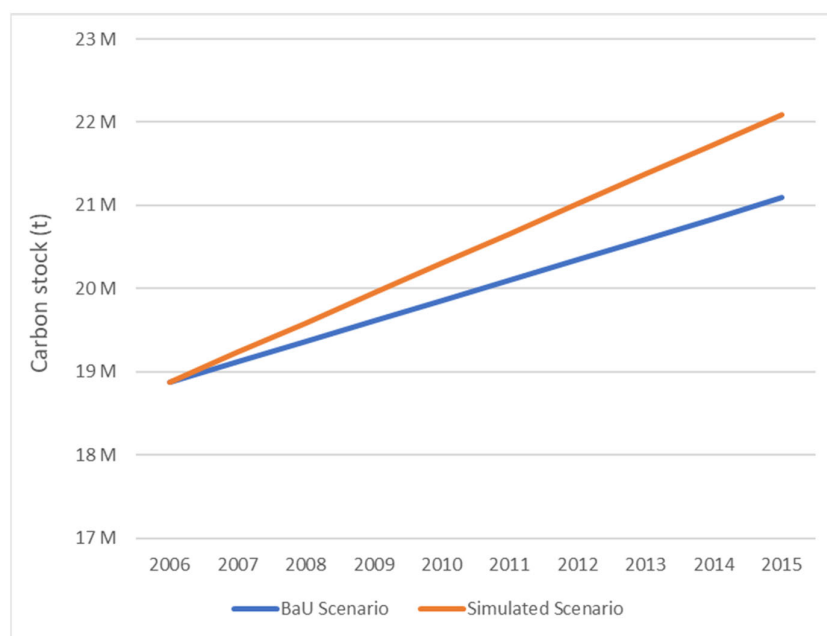

Figure 4. Graphical representation of f(x) and g(x) functions of BaU and simulated scenarios respectively.

Then, the number of potential carbon credits (PCC) was 16,500,898, which correspond to potential anthropogenic avoided emissions in terms of t CO_2 eq. Therefore, the number of carbon credits generated (NCCG) will be between 3,300,179 and 14,850,808 (equivalent to t CO_2 eq.) in the simulated 10-year period in the region. Consequently, the monetization of the calculated NCCG in the region based on the carbon price of forestry carbon markets analyzed was between 55.5 and 250 million €.

The model developed is easy to apply and offers results from a conservative point of view, so as not to overestimate the NCCG. The fact that it is easy to apply creates the possibility of using it as a system of measurement, reporting, and verification (MRV) in systems such as REDD + in those countries that, due to a low degree of deforestation, the

cost of MRV is greater than the economic compensation of REDD + such as indicates Köhl et al. [26]. Despite these advantages, the model developed has some drawbacks that should be improved in future work. Some of these drawbacks are: (a) that the NCCG range is very wide; (b) soil carbon and detritus are not quantified; and (c) the model does not consider other carbon losses such as that caused by pests or other extreme weather conditions.

3.3. Carbon Fixation in Relation to Total GHG Emissions

The quantification of total gross GHG emissions in Valencia was 35.5 million t CO_2 eq. divided between direct and diffuse GHG emissions. The highest emitter sector was "Energy" with around 75%, followed by "Industrial processes and product use" and "Agriculture" with 10% each, and "Waste" with 5%.

Direct GHG emissions from 178 EU ETS facilities in the region emit 8.9 million t of CO_2 eq. [54]. The main contributor is the ceramic sector, with 33% of the total direct emissions followed by the clinker sector with 21% and electricity generation with 18%.

Diffuse GHG emissions are estimated as 26,622,550 t CO_2 eq. across every municipality in the region.

Therefore, the annual CO_2 fixation by living biomass in forests compensate 9% of total gross GHG emissions and 15% of diffuse emissions that have no compensation carbon market today.

3.4. Potential of Mediterranean Forestry for Offsetting GHG Emissions

The number of carbon credits generated (NCCG) calculated by the application of the methodology developed for the regional case of Valencia, would allow compensation of between 330,018 and 1,485,080 t CO_2 per year. This would suppose a compensation potential between 1.2 and 5.6% of total diffuse GHG emissions.

Regional compensation of GHG emissions would produce immense positive benefits for society and the environment at local and regional levels: promoting actions maximizing forest cover on soils with marginal agricultural potential while concurrently increasing livelihoods and mitigating climate change, as demonstrated by Tong et al. [56]; creation of jobs linked to rural activities (rural development); minimizing natural disaster risks; conservation of biodiversity and natural habitats; revaluation of the territory and its resources; and promotion of low-carbon value chains (bioeconomy), in summary, improving the resilience and sustainability of socio-ecological systems [57].

Furthermore, although in a local carbon market there may be different stakeholders with diverse interests and different goals, a win-win solution is possible and beneficial for society [58]. Finally, the implementation of this model in other regions requires the availability of data inputs. Data sources have to provide information regarding forest characterization (such as occupied area), annual growth in living plant biomass, forestry treatments or actions (such as afforestation, reforestation, plantations, and harvesting) and at least 10 years of wildfire historical data. Additionally, assumptions considered in Section 2, such as the average of biomass consumed during wildfire due to severity, must be satisfied.

4. Conclusions

A quantification of CO_2 fixation by living plant biomass within the forestry sector has been undertaken with high spatial resolution in a representative Mediterranean region with a clear lack of forest management (Valencia in Spain).

The methodology developed permitted monetization of CO_2 fixation by forests with a new approach adapted to Mediterranean conditions, which takes into account the anthropogenic avoided emissions by sustainable forest management to actively prevent wildfire. In this way, a simulated scenario with forest management has been used to calculate the generation of carbon credits of avoided CO_2 eq. emissions and to compare

with a business as usual scenario. In addition, a literature review of the existing forest-based carbon markets has been carried out to estimate an average carbon credit price equivalent to one ton of CO_2 eq.

The application of this methodology to the study case of the Valencia region has allowed a total monetization of between 55.5 and 250 million €, corresponding to 16.5 million of potential carbon credits generated equivalent to anthropogenic avoided emissions over a 10-year period in terms of t CO_2 eq. Thus, the methodology developed would be used as a system of measurement, reporting and verification (MRV) in systems such as REDD + in those countries that, due to a low degree of deforestation, the cost of MRV is greater than the economic compensation of REDD + system.

Finally, the comparison of carbon credits generated with total GHG emissions has highlighted the potential for offsetting between 1.2% and 5.6% of diffuse GHG per year (emissions without regulated carbon market) at the regional level. As future work, a quantification improvement of diffuse GHG emissions at the local level is necessary to enable the establishment of a voluntary carbon market in Mediterranean forest regions. On the other hand, the fixation produced by the soil and plant detritus should be added to the quantification of the carbon fixation of the forest land. Finally, more efficient silvicultural measures to enhance carbon sequestration and reduce wildfire risk should be studied and quantified in order to reduce the uncertainty range of the nnnumber of carbon credits generated (NCCG) with respect to the potential carbon credits (PCC) calculated.

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